Report on the NASA LBA-Ecology Light Aircraft Remote Sensing Instrumentation Workshop

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Abstract

NASA's LBA-Ecology Project sponsored a two-day workshop, entitled the "NASA LBA-Ecology Light Aircraft Remote Sensing Instrumentation Workshop," at the Inn and Conference Center of the University of Maryland during October 6-7, 1997. The workshop was designed to explore the current "state-of-the-art" in operational small aircraft remote sensing instrumentation and to recommend several optional packages that meet the projected remote sensing (RS) needs of NASA's LBA-Ecology Project in the Amazon area. Experts in airborne remote sensing from NASA, USDA, universities, and private companies provided combined experience in excess of 200 years of airborne remote sensing. An overview of LBA and NASA's role in the LBA project set the focus for the required capability of the RS package, which may be developed in multiples for co-location at several intensive study sites for the three to five-year period of the study. The workshop was very productive, as three primary instrument packages were "designed." The proposed configurations were based on "off-the-shelf" products, and approximate costs were developed. A nominal $500K targeted cost for instrument package development, including components and integration for a single (first) operational unit was used the to scope the discussions. However, integration costs for the aircraft sensor package were not well developed during the meeting, as the discussion focused on the available instrumentation that should be considered for inclusion in such a package. The capabilities of all three proposed packages exceed those of packages that have been flown on small aircraft in previous field campaigns, but it will be essential for the LBA-Ecology science community to clearly identify the remote sensing parameters and products needed in order to make a final selection of sensor components to be included in the instrument package to be developed. The workshop participants made a concerted effort not only to list the sensor characteristics and other engineering concerns, which was the concentration of the expertise at the workshop, but also to identify the measured parameters and potential usefulness of the proposed sensors to the ecological scientific community. This report summarizes the discussions, issues and recommendations associated with several topics relating to the development of an operational small aircraft remote sensing instrumentation package. Two appendices follow the main report: I) the Workshop Agenda, and II) a List of Participants.

Introduction

The Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) is an international research initiative led by Brazil. LBA is designed to create the new knowledge needed to understand the climatological, ecological, biogeochemical, and hydrological functioning of Amazonia, the impact of land use change on these functions, and the interactions between Amazonia and the Earth system. NASA's LBA-Ecology Project is a component of LBA that will focus on terrestrial ecology and land cover/land use change.

The challenges of working at diverse sites scattered throughout the Amazon area make it difficult to monitor and compare study sites without remote sensing as a tool. It may be necessary to deploy several light aircraft for measurements in key locations for rapid response and frequent measurement capability at local sites. These aircraft would carry integrated, well-tested remote sensing and ancillary instrument packages with instrumentation similar or identical to each other. The proposed system must respond to the needs of today's ecosystem scientists for local remote sensing data to complement ground and satellite investigations. In order to cover such a large number of sites spaced so far apart, the instrument package must be portable and versatile, pragmatically functional, and relatively inexpensive so that it can be duplicated.

The purpose of this workshop was to examine existing and somewhat readily available hardware that could be assembled to produce an integrated remote sensing instrument package. The package should be suitable for mounting on light aircraft, for use in routine remote sensing missions over selected LBA targets and should have application potential for other NASA planning activities requiring low-cost remote sensing. The workshop purpose also encompassed identification of package measurement capability in terms of ecological products. System design was driven by the requirement that it could be assembled from off-the-shelf instrument components, take a variety of basic measurements simultaneously, and be mounted on locally available aircraft. Desirable features for individual instruments for the package were low cost, easy deployment, well-characterized performance, good calibration, light weight, and low power consumption.

To accomplish these objectives, participants in this meeting were invited based on their knowledge and experience with remote sensing hardware and applications of this type of instrumentation. In an attempt to diversify the functionality and capability of this sensor package and to get a wide perspective on solutions, participants were invited from multiple agencies and organizations (universities, USDA, NASA, and commercial industry). This resulted in an invitation list consisting mainly of instrument engineers and technicians with a few researchers/scientists (see Appendix III). Several instrument or vendor representatives were invited to aid in understanding technical specifications and in the identification of capabilities, but the invitees were instructed that it was not a forum sales or marketing opportunities; however, few were able to attend. Participants were asked to share their knowledge about the advantages and disadvantages, costs, and availability of various relevant instruments, mounting platforms, and small aircraft. The participants who had recent experience with designing, developing, integrating and deploying integrated small aircraft packages were asked to present a brief overview of their system(s) and what they saw as critical issues.

In order to meet as many remote sensing needs as possible, the instruments that participants attempted to investigate included:

- Thermal radiometers
- High spatial resolution spectrometers
- Cosine Collector Spectroradiometers or Sun Photometers
- Multi-angular radiometers
- CCD and video imagery instruments
- Lidars and/or range-finders
- Radars and passive microwave instruments
- GPS units and CDI’s (Course Deviation Indicators)
- Cameras

with allowances made for possibly incorporating automated CO_2 and other gas sampling instruments onto the same aircraft platform.

In order to develop a viable sensor package several issues had to be addressed so the constraints and requirements would be understood. They were:

Types of aircraft that might be available in Amazonia
Aircraft operational limitations
Aircraft functional limitations
Basic measurement capability
Ancillary data and data systems
Field operation limitations
Previous experiences
Available operational sensors and equipment

Discussions of these issues raised even more questions and several action items and charges resulted.

Although the issues above are presented in an organized list, the order in which they were developed and discussed was not. The workshop was an iterative process, which does not lend itself to a concise description of the results and ideas. With clarity in mind, the specifics of this report will be organized around these issues and will be developed in the order listed. The suggested instrument packages that followed from looking at these issues will be presented from three perspectives to allow the reader to view the information the way that seems most logical to him/her. Following this section is a summary of recommendations and outstanding issues. Conclusions on the final specifications of an instrument package must await specification of requirements by the discipline scientists and clarification of the funding that will be available for the initial instrument development and duplicate instrument production.

Types of aircraft that might be available in Amazonia

In order to assess a real constraint on the total size, weight, power consumption, and mounting options, participants discussed what types of small aircraft would most likely be available for rent in Amazonia. Initial research using Internet searches across Brazilian web pages yielded links to several flying clubs in the more developed areas of Brazil. The aircraft listed ranged from the ever-popular single engine Cessna 182 and Piper Cherokee to the larger Piper Seneca-2. Some participants suggested that LBA-Ecology explore the option of using a larger aircraft already outfitted for remote sensing and retaining it on a long-term contract to avoid many of the operational and functional limitations. Another issue raised was NASA's policy regarding a co-pilot in a multi-engine plane and how this might preclude NASA employees from flying along in aircraft operations. This constraint will have to be investigated if a multi-engine aircraft is used. However, concern was expressed about availability of specialized aircraft and of larger aircraft in some of the more remote locations. It was decided that participants should follow the conservative route and limit capabilities to single engine aircraft such as the Cessna 182. A subsequent email received from Bernardo Rudorff, Director of the Remote Sensing Branch at INPE, indicated that the Cessna 182 is the most likely option. Some agreed that this would be a good "design to" constraint, since the Cessna 182 is also readily available in North America.

Aircraft operational limitations

Due to the frequency of data collection and the enormous distances between study areas and sites, it was obvious that the sensor packages would usually be flown on small, low-cost rental aircraft operating from local airports. This implies that the configuration would be limited very minor or no structural modifications to the aircraft. Aircraft range limitations with a cargo such as the sensor package may force a trade-off between number of passengers and flight duration. A discussion regarding typical payload/flight duration/altitude trade-offs indicated that, for the short flight-lines and windows of opportunity that will most likely exist due to cloud formation, the use of a single engine Cessna is not an issue. The size of the aircraft, such as the Cessna 182, will limit the number of instrument operators to one. It was suggested the package could be flown without an operator in ER-2 fashion (pilot only), if the system could be automated enough that the pilot could just turn it on and fly to the flight lines pre-programmed into the CDI. This option received mixed reactions, based on the potential need for an educated assessment of conditions for remote sensing on the fly.

Aircraft functional limitations

Using a small, low-cost rental aircraft poses several inherent functional limitations. Issues such as low power, low cargo mass and volume, lack of instrument mounting hard-points or large ports for optical instruments, and a nonexistent or inadequate INU (inertial navigation unit) or FMU (flight management unit) were identified.

The potential lack of adequate instrument/experiment power led to several suggestions, although no total power requirement has been calculated for any of the three suggested packages:

1) Only rent planes which have the necessary power capabilities and harnesses;

2) Provide funds to upgrade an aircraft's generator and install needed harnesses and interfaces;

3) Take appropriate measures to reduce the system's power requirements to that of a stock Cessna 182's excess power;

4) Provide additional instrument package power in the form of a battery or UPS (Uninterruptible Power Supply). The latter would certainly require special effort to reduce system power consumption. One participant raised the issue of having a hazardous material, such as the UPS's lead acid battery, in the passenger compartment and this issue should be investigated with regard to Brazilian civil aviation law.

Low cargo mass is a non-negotiable constraint that will require close attention in the system design to make sure redundancy and excess instrument and rack materials are removed. A related issue is the physical size of the system. The sensor package portion of the system will have very limited space in whatever hole or pod it is mounted. Control and data system rack size is an issue, since the aircraft (Cessna) is very narrow, with a low ceiling. It was suggested that mechanical drawings of the aircraft should be obtained to provide information during any future design brainstorming sessions.

The low cargo volume constraint led to discussions about the lack of instrument mounting hard-points on the outside of a rental aircraft , as well as the lack of large ports for optical instruments. Since no one expected to find a large camera port in a rented Cessna 182, participants focused on mounting equipment in ways which might protrude from the aircraft. Participants were unsure about Brazilian civil aviation law restrictions on mounting equipment to the outside or underside of an aircraft in a way which might interfere with the aerodynamic characteristics of the Cessna 182, and this issue was indicated as something to investigate further. Four primary options were proposed for solving this problem and some combination may be the best solution if a package with a large number of sensors is selected:

1. Use a pre-approved aerodynamic sensor pod similar to EPA's Enviropod, which was flown strapped on the bottom of a Cessna 182.
2. Develop a "baggage door insert" which would house the fore-optics in a fiberglass aerodynamic faring that bulges out from the baggage door area. Xiu Hong Sun mentioned that TerraSystems has an FAA-approved replacement baggage door for a Cessna.
3. Replace a cockpit door/window with a similar faring, as in option 2.
4. Use fiber optics to bring light through small holes that may exist. This was identified as a good option for non-imaging systems only.

While these seem to be reasonable options, it was agreed that Brazilian civil aviation law may either be a show-stopper or may add considerable cost for approval. This issue will have to be investigated before a design is begun.

Small rental Cessna 182's generally do not have an adequate INU or FMU by which the pilot can fly precise lines. They also rarely have a data output interface, such as ARINC429, so flight position and attitude can be logged in the data stream to allow geolocation of the data and images. This was not seen as a problem, since everyone agreed that a good CDI and precise attitude and position would be required and most available small aircraft INU's do not provide the precision and accuracy. It was recommended to provide this capability as part of the carry-on package.

Basic measurement capability

A mandatory issue to be resolved before hypothetical instrument packages could be discussed was, "What do we want to measure?" This was somewhat difficult since no one felt the workshop participants could speak for the LBA-Ecology Science Team, particularly since the Science Team had not yet been selected. Instead, participants used a combination of experience from previous large-scale field campaigns such as BOREAS and FIFE and other flight programs within which several participants had been involved, in addtion to the information from the "Role of Remote Sensing in LBA" section of NRA97mtpe02 (see: http://www.hq.nasa.gov/office/mtpe/nra97mtpe02/remote.html).

Parameters such as Spectral Radiance and Irradiance in the Visible (VIS) through Infrared (IR) spectrums and Microwave/Longwave emissions or reflectance were listed as measurements of interest; and optical sensing was expected to be a must-have in an RS package. The issue of spectral resolution and coverage was addressed by offering varying levels of capability in this area in the proposed packages. Measurement techniques such as Lidar and Radar were identified as being of interest to researchers trying to obtain biomass, topography and canopy structure. Imaging vs. profiling was briefly discussed, but it was generally agreed that images, if affordable, would serve a much broader need and could provide an "historical" site monitoring value as the project progressed. Finally, the team felt that the design should leave open the possiblity of aerosol/flux instruments in the package to help obtain the highest scientific return per flight hour.

Most of the workshop participants had experience with optical sensors, both passive and active (LIDAR). Unfortunately, the invited experts in Microwave/Longwave and Radar were unable to attend, and an outstanding issue is to investigate options for Radars that might fit on a small aircraft and provide useful biophysical data. For these reasons, the potential sensor packages are strong in optical and Lidar with no mention made of radar. Subsequent investigation has shown that there are no known longwave scatterometers that can be readily mounted on a small aircraft such as a Cessna 182. There are some such instruments that have been flown on helicopters, and with some development activity, radar instruments could likely be adapted to light aircraft operation. One of the key practical problems is the size of the antenna that would need to be mounted beneath the aircraft body.

Ancillary data and data systems

Several ancillary data products were identified as important to post-flight processing and should be included in whichever of the optional packages is selected for development:

- Video ground/sky-truth - use a bore-sighted down-looking color-video camera with a field-of-view (FOV) comparable to the other sensors to see where/what the sensors were looking at and an up-looking color-video camera with a wide-angle lens (~165-180^o FOV; TBD) to document cloud and smoke distribution, since it will be nearly impossible to find "golden day" conditions that investigators have often waited for in aircraft campaigns in temperate climates.

- Accurate and precise position - Use a GPS/GLONAS satellite receiver to allow geolocation and accurate time stamping of data. This information will also feed into a CDI and/or Moving Map Display for the pilot and operator.

- Accurate and precise attitude - Use one of the new solid-state gyros to obtain acceptable performance for frame images or a fiber optic gyro (FOG) to obtain necessary precision and low-drift for pushbroom images and scanning lidar/rangefinder images.

The design of the data system came up early due to issues about the number of operators, power and weight, and Brazilian law concerning remote sensing data collection and distribution. It was generally felt that the data system should be completely integrated into one computer system to reduce power, size, weight, operator workload, and to provide one integrated data file that could be sent to the proper Brazilian archive. Some participants expressed a concern that many of the proposed instruments come with their own data systems and integrating them into one system could be costly in terms of manpower on the initial prototype. This issue was left open-ended, to be resolved once all instruments were selected. Ease of integration may be a factor in instrument selection.

Field operation limitations

Several issues and considerations were brought up concerning operations in potentially hostile (to delicate equipment) environmental conditions. Given the potential lack of a hangar to work on installation and removal and issues of availability due to the aircraft being used for other work, everyone agreed that the package should be easy to install, remove and calibrate. It was pointed out that one way to improve ease of calibration is to insist that the instruments be independently radiometrically stable. Environmental considerations such as rain, humidity, dust, and heat prompted suggestions that all packages be environmentally sealed, temperature stabilized, and possibly dry nitrogen purged. An expected lack of clean service laboratory space and parts supply sources prompted requirements of system reliability and serviceability. Consequently, instruments that have no proven track record and are "experimental" will most likely not be considered. To improve serviceability, it was suggested that a modular interface might make instrument swaps for service or reconfiguration much faster and might not compromise package availability in the event of an untimely failure of a single instrument. This approach would also allow multiple sensor locations to be utilized to reduce the aperture size at an available mounting location.

Available Operational Sensors and Equipment

As a precursor to the workshop, a pre-workshop remote sensing brainstorming session was held at Goddard Space Flight Center during June of 1997. In response to the June session, organizers received several papers and data sheets describing operational remote sensing systems. Philip Dabney/920.3/NASA-GSFC was charged with the task of compiling this information into a database or matrix of sensor parameters and of performing a thorough search for information on additional systems. During the October workshop, several sources of available sensor information were used:

- Individual knowledge and familiarity with a sensor
- Philip Dabney's Airborne Sensor Database/Matrix containing relevant highlights from the next two sources and general Internet and literature searches.
- Tables and Matrices of Airborne Sensors compiled by others
    1. http://www.eol.ists.ca/documents/IS-Team-Canada/Can-Activities-ImagSpec.book_96.html#HEADING95
    2. http://www.geo.unizh.ch/~schaep/research/apex/is_list.html
- Comprehensive surveys and reports written by others such as Herbert J. Kramer's "Observation of the Earth and Its Environment - Survey of Missions and Sensors." This book contained more information than could be reasonably absorbed.

Since final instrument selection has not been made, the LBA-Ecology Project Office will continue to compile potential sensor candidates.

Results - Optional LBA Light Aircraft Remote Sensing Package

The following pages contain tables of the three options developed for LBA Light Aircraft Remote Sensing Packages. The first table is an attempt at presenting the fundamental system characteristics information without the details that clutter the full-information tables. The full-information tables are the final working view-graphs from the workshop, containing all the modifications and iterations made by participants. In the detailed tables, specific sensors were identified as possible candidates or as good examples of the type of instrument participants wanted for that measurement — not as firm recommendations. Final prices and availability are still pending for most of the items. Prices given on individual systems/instruments were ball-park and could carry up to a 25% uncertainty. Additionally, participants did not try to attach a manpower estimate to the task of designing and building the first unit. A few educated guesses placed the task at approximately one person-year of an engineer/technician's time.

At the time of the workshop, there were no small, "off-the-shelf" commercial domestic hyperspectral sensors. The market will be surveyed again before an actual design meeting takes place.

General Characteristics for Three Potentially Viable Light Aircraft Remote Sensing Instrument Packages

Package	Capabilities	Approx Cost $US
Good	Spectral Radiance Image($L_{ë}$) (4 TM VIS-NIR bands) Canopy/Surface Topography Profile GPS positioning: 15m / INS attitude: 0.5 degrees	250K
Better	Hyperspectral Radiance Image($L_{ë}$) (VIS-NIR) Limited 4-band BRDF profile(+-45,nadir) (VIS-NIR) Canopy/Surface Topography & Stand Heights Profile GPS positioning: 1m / INS attitude: 1mRad	380K
Best	Hyperspectral Radiance Image($L_{ë}$) (VIS-NIR) Short-wave IR Radiance Image($L_{ë}$) (2.5-4ìm) Limited 4-band BRDF profile(+-45,nadir) (VIS-NIR) Surface Humidity/Surface Temperature Image Images of Canopy/Surface Topography & Stand Heights GPS positioning: 1m / INS attitude: 0.01mRad Multispectral Digital All-Sky Camera	460K
All packages	Down-welling VIS-NIR Spectral Irradiance ($R_{ëdown}$) Color Video for Visual documentation and bore-sighting All-Sky Camera (for Cloud cover and smoke mapping) 1-4 m image spatial resolution Atmospheric H_20 Surface Temperature Canopy Temperature Course Deviation Indicator for Pilot (CDI) with optional Moving Map Display Integrated Data system (1 data file with all parameters) with GUI	Included above

Remote Sensing Instruments (Sensors) for LBA Light Aircraft Remote Sensing Package

	Instrument Examples / Name(s) / Cost		
Measured Parameter	**Good**	**Better**	**Best**
Down-welling Spectral Irradiance ($R_{ëdown}$)	Cosine Collector fiber-optically fed to focal plane of multispectral cameras or Compact FO Spectrometer/S2000/ $4K	Cosine Collector fiber-optically fed to focal plane of imager and Compact FO Spectrometer/ S2000/ $4K	Cosine Collector fiber-optically fed to focal plane of imager and Compact FO Spectrometer/ S2000/ $4K
Upwelling Spectral Radiance Image($L_{ë}$) GREEN(TM) RED (TM) NIR (TM) PAR (TM) *SWIR 1-2um** *SWIR 2.5-4um***	Discrete Digital Cameras with Optical Filters + nadir Exotech Radiometer/ADS, Positive Systems, or TerraSystems /150K, 250K, 150K (+ 7K/camera) + 7K	Hyperspectral*** Pushbroom Imagers for VIS-NIR + nadir and "45^{o}" Exotech Radiometers /CASI, AISA, or FLDS/?, 250K, 100K + 20K	_ Previous + ADS SWIR camera/CASI, AISA, or FLDS/?, 250K, 100K/+70K or; use IFRI to gain 1-2um region /350K?

* Only IFRI from STL of Hawaii has this as off-the-shelf in their imager (?)
** Coverage is given with a separate Frame Camera from ADS (Inframetrics; ?)
***In full spatial sampling mode the AISA & CASI must sub-sample the spectra due to bandwidth limitations

Remote Sensing Instruments (Sensors) for LBA Light Aircraft Remote Sensing Package (cont'd)

	Instrument Examples / Name(s) / Cost		
Measured Parameter	**Good**	**Better**	**Best**
Atmospheric $H_2$0: (for Atmospheric correction of VIS-NIR imagery) **Split Window in TIR 10.5-11 um, 11.5-12um**	2 - Small IFOV TIR sensors with split window filters/ IRT/10K	2 - Small IFOV TIR sensors with split window filters/ IRT/10K	Split Window TIR Imager(s)/?/?
Surface Humidity	None	None	Gained from Split Window TIR Imager above
Surface Temperature	Profile from above sensors	Thermal Imager	Image from TIR imager above
Canopy Temperature	Off-nadir IRT/5K	Off-nadir IRT/5K	Off-nadir IRT/5K
Canopy/Surface Topography (Transmit energy limits altitude to <3000ft AGL)	Profile along flight line using a 1-5KHz 1-hit rangefinder/?/4K	Profile along flight line using a 1-5KHz 2-hit rangefinder/?/10K? (2hit gives top of canopy topography and stand heights)	Spatial Scan of a 1-5KHz 2-hit range-finder to get ?image? of previous capability/?/$30K?
All-Sky Camera (for Cloud cover and smoke mapping)	Color video CCD camera with Fish-eye lens/Pulnix?+Nikon/5K	Color video CCD camera with Fish-eye lens/Pulnix?+Nikon/5K	→Previous or Multi-spectral Digital Frame Camera with Fisheye Lens/20K?

Remote Sensing Data System for LBA Light Aircraft Remote Sensing Package

	Examples/Name(s) / $		
Interface or Feature	**Good**	**Better**	**Best**
GPS	GPS+GLONAS receiver with 15m uncertainty	→ Previous, plus *Post Processed differential GPS using GPS ground stations at each super-site or use possible real time broadcast of RTCM from a service in Brazil? **: 1m uncertainty**	Set up our own RTCM broadcast network: 1m uncertainty (Very expensive)
INS	Commercial INU/10K: 0.5 degree accuracy	A Collins/Boeing Midget IMU/25K: 1-mRad? precision/ accuracy	ASAS Fiber-Optic-Gyro (FOG)/35K: sub- mRad? precision/ accuracy
Color Video for Visual documentation and bore-sighting	Must have for all systems/5K		
Data Acquisition Storage and system control	Issue exists regarding using OEM CPU's and synchronizing them or saving weight and power by paying more in development costs for an integrated data-system/$?		

* Labor cost will be higher!

Navigation System for LBA Light Aircraft Remote Sensing

	Options/Name(s)/Cost		
Interface or Feature	**Good**	**Better**	**Best**
Course Deviation Indicator for Pilot (CDI) with optional Moving Map Display	Commercial CDI system/$6K	Commercial CDI system with Moving Map Display/$10K	Commercial CDI system with Moving Map Display/$10K

Summary of Recommendations and Follow-up issues

The following lists of Recommendations and Follow-up issues are arranged approximately in order of descending priority.

- **Before LBA-Ecology can proceed with instrument selection, package design, and building a prototype, several issues and questions must be addressed by the Science Team. These questions will ensure that the project does not buy capability that no one will use and also that some important measurements will not be missed. The questions to asked at the next LBA-Ecology Science Team Workshop are:**

  - ➢ What are the parameters that LBA Science needs? How can aircraft Remote Sensing fill in the gaps/chasms?

  - ➢ As a tool for generating thought and discussion at the workshop, participants gave most of these examples of potential information obtainable through the proposed Remote Sensing packages:

    - LAI, NDVI, fPAR/PAR, Chlorophyll, Albedo, BRDF, Water Optical Properties
    - Satellite Validation and Scale Up/Down
    - Generalization of Point Measurements
    - Surface Temperature, Canopy Temperature
    - Canopy height and closure, topography, biomass (Temporal variability)
    - Cloud cover, Smoke mapping, Fire mapping (active and post fire)
    - Atmospheric H_20, Surface Humidity

  - ➢ At what locations and scales are these parameters needed? (Tower sites, field sites, transects, etc.)

  - ➢ To what precision, accuracy, spatial and temporal sampling do investigators need to obtain these parameters? Do investigators need images or just line profiles?

  - ➢ What wavelength regions are necessary to derive these parameters? (VIS, NIR, SWIR, TIR, Microwave)

  - ➢ Is multispectral adequate or should the package include a hyperspectral spectrometer? (<10nm)

- **Aircraft Recommendations and Issues**

- The NASA LBA-Ecology Project should be conservative and design a package that can be mounted on a single engine rental aircraft such as the Cessna 182. We have identified the Cessna 182 as the most likely aircraft in some of the remote sites.

- Identify exact model of aircraft to be rented, since a large variation in capabilities and options exists within the Cessna 182 model line, and obtain: available power, cargo mass and volume, INU and CDI capabilities, mounting options and limitations.

- Investigate Brazilian civil aviation law restrictions on; mounting equipment to the outside or underside of an aircraft externally mounted pods (e.g., Enviropod's EPA), the use of modified baggage/entry doors (such as TerraSystems' plexiglas bugle that fits in the baggage compartment), and limits on modifications on small aircraft.

- Clarify NASA regulations on NASA employee official/working presence on an aircraft without a co-pilot

- The package should provide a CDI and/or moving map display and software to allow fast programming of flight lines for these devices. It is unlikely that rental aircraft would have the capability needed for precise re-flights of the same lines. One option suggested was to adapt Wallops Flight Facilities' CDI program, integrate it into the package data system, and give the pilot a separate display.

- **Sensor Package Recommendations and Issues**

- All instruments used must be operational, not experimental, and have a history of reliable field performance and stable calibrations. The instruments should be "catalogue" items so multiple copies can be purchased.

- Individual instruments should have modular aircraft-independent interface to allow fast installation, removal, servicing and upgrades. The interface should be mounted in such a way that eliminates the need for aircraft modifications (pod or modified replacement doors) and can be entirely removed and placed on another similar aircraft. Instruments or packages should have environmental seals and temperature and humidity control. A calibration method should be devised that will eliminate the need for removing the sensors from the aircraft.
- Use a multi/hyperspectral imager for the VIS-NIR that at a minimum provides Landsat TM/ETM VIS-NIR coverage for scale-up and cal/val activities. A single band SWIR imager would be of great interest for atmospheric correction and soil classification.

- Down-welling spectral irradiance is a must. This will allow better illumination modeling and possibly direct calculation of reflectance.

- Provide canopy heights, roughness, and limited topography by using a low-cost two-hit laser range-finder.

- Image rectification and registration are important and should be done using post-processing instead of a large, power-hungry stabilized mount. The method used to accomplish this will be based on a combination of INU attitude, differential GPS data, and image texture correlation.

- Video ground and sky-truth are important. Use a bore-sighted, down-looking, color-video camera with a field-of-view (FOV) comparable to the other sensors to see where/what the sensors were looking at and an up-looking color-video camera with a wide-angle lens (180^{o} FOV?) to characterize cloud and smoke cover.

- A nadir and an off-nadir thermal IR spot measurements or profilers are a minimum for ground and canopy temperature measurement. An imager would add a lot to the science.

- Reserve space in the design of the package for inclusion of gas flux instrumentation.

- Further explore the inclusion of a vegetation-radar in package.

- Update the database of potential sensors, particularly: operational status of sensor, environmental restrictions, calibration stability, cost, weight, power, size, and purchasing lead-time.

- Data system and software requirements need to be identified. Should there be one integrated data system versus a distributed system with each instrument manufacturer's supplied data logger? Should there be one inclusive data file with all data and housekeeping?

- INU and Differential GPS requirements need to be derived from Science Team requirements for precision and sensor selection. A method of differential GPS correction needs to be identified. A slight possibility exists that a broadcasted correction is available but most likely the project will have to set up ground stations (where?).

Appendix I.

NASA LBA-Ecology Remote Sensing Instrumentation Workshop Agenda

<u>Monday, 6 October</u>

8:00 AM	Registration
8:30 AM	Introduction to NASA LBA-Ecology Project - LBA Experiment overview - LBA-Ecology Module overview - Types of measurements needed for LBA-Ecology - Need for standard replicable package - Implementation considerations and constraints
9:30 AM	Questions to be addressed by Workshop - Core measurements - Core instruments - Existing applicable instruments - Previous experiences - Design considerations relative to operations
10:00 AM	Definition of light aircraft in the Amazonia for LBA Availability and characteristics of Brazilian aircraft -Some RSS AC exist now (How many? Where?) -We probably need to rent non-modified AC at some locations
10:15 AM	Break
10:30 AM	Discussions of experiences with light aircraft remote sensing (organized by spectral regime: optical, lidar, thermal, microwave, radar; and ancillary equip.) - Design, instrumentation, and capabilities - Aircraft and mounting platforms - Weight, versatility, other implementation considerations - Pitfalls and lessons learned - Operational scenarios and mission considerations
12:00 Noon	Lunch
1:00 PM	Continued discussions of experiences with light aircraft remote sensing

2:00 PM	Group discussion of key characteristics & constraints for an LBA light aircraft remote sensing package - Weight (range: ? - ? kg) - Size (Need to fit a range of available AC) - Ease of Installation (quick AC changes & service) - Power (Available Aircraft + package batteries) - Cost (budgetary limits of LBA for RSS) - Low maintenance (calibration, reliability, ruggedness, serviceability)
3:00 PM	Break
3:15 PM	Description of anticipated minimal capabilities required for LBA-Ecology Projected list of measurements to be made
4:30 PM	Presentation and refinement of AC Instrument Information Matrix
5:00 PM	Adjourn

Tuesday, 7 October

8:30 AM	Review of anticipated minimal capabilities required for LBA-Ecology Review of projected list of measurements to be made
8:45 AM	Presentation of updated Instrument Information Matrix, including information gathered at yesterday's meeting
9:00 AM	Development of instrumentation package options
10:30 AM	Break
10:45 AM	Continuation of development of instrumentation package options
12:00 Noon	Lunch
1:00 PM	Continuation of development of instrumentation package options
3:00 PM	Break
3:15 PM	Conclusion of options development. Preparation of presentation for LBA-Ecology Science Team
5:00 PM	Adjourn

Appendix II

List of Participants
Remote Sensing Workshop
6 - 8 October 1997

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